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Mitigating the Loss of Navigational Awareness While Flying With GPS and Moving Map Displays Under VFR

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Abstract

An earlier study demonstrated how reliance on GPS and moving map displays could significantly degrade pilot navigational awareness when flying under VFR (Casner, 2005). It was hypothesized that the drop in navigational awareness was due to the passive role assumed by pilots when using equipment that automates the navigation task. In this follow-up study, eight pilots used GPS and moving map displays to navigate between the same circuit of checkpoints used in Casner (2005) while performing one additional task: while en route between each pair of checkpoints, pilots were asked to choose and point out three geographical features. The research question was whether or not a greater involvement in the navigation task would result in better pilot performance on the same test of navigational awareness used in Casner (2005). Using the data from Casner (2005) as a control, a significant advantage was indicated for pilots who pointed out geographical features while navigating using GPS and moving maps. This suggests that simple practices that place the pilot in a more active role can help mitigate the "out-of-the-loop" phenomenon associated with using GPS and moving maps.

Introduction

Despite the many arguable advantages of using GPS and moving map displays, a previous study has shown how reliance on GPS and moving map displays can significantly degrade pilot navigational awareness (Casner, 2005). In that study, sixteen pilots were asked to fly, as accurately as possible, over a circuit of checkpoints in an unfamiliar area. Eight of the sixteen pilots were provided with a sectional chart (the Pilotage group). The eight remaining pilots were provided with the same sectional chart and a panel-mounted GPS receiver featuring

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a color moving map display (the GPS/Map group). Navigational accuracy was recorded at each checkpoint in the circuit. After navigating along the circuit, all pilots were unexpectedly asked to fly the same circuit again. This time, the Pilotage group was asked to navigate around the circuit without the use of the sectional chart, while the GPS/Map group was asked to navigate without either the chart or the GPS and moving map. Navigational accuracy was measured again for each checkpoint on this second trip around the circuit. The GPS/Map group performed significantly worse than the Pilotage group when navigation resources were taken away. Two pilots who used the GPS and the moving map were unable to find their way to the starting point of the circuit. Other GPS/Map pilots made large errors in navigating to individual checkpoints.

A simple depth-of-processing explanation (Craik & Lockhart, 1972; Glenberg, Smith, & Green, 1977) was offered for the degraded performance among pilots who used GPS and moving maps. Pilots who used only the sectional chart for navigation were forced to take careful note of geographical features and actively use them to locate checkpoints. This navigational method required deep processing of geographical features and resulted in a high degree of familiarity with the area. Pilots who relied only on the GPS and moving map were free to set aside the sectional chart and largely ignore geographical features as they were automatically guided to each waypoint by the GPS computer. When confronted with a situation in which familiarity of the area was suddenly needed, pilots who were actively engaged in the navigation task performed well. Pilots who relied on GPS and who did not actively participate in the navigation process performed poorly. Endsley (1996) cited a number of studies in which a similar effect has been demonstrated when human operators are combined with automated systems.

Mitigating the Negative Effects of GPS and Moving Maps

Given the many advantages of GPS and moving maps (e.g., locating the nearest airport during an emergency), it is difficult to argue that pilots should not use them. A more sensible approach is to ask: Are there simple practices that pilots can adopt that allow them to take advantage of the beneficial features of GPS and moving maps, yet avoid the "out-of-the-loop" phenomenon?

In this study, a third group of eight pilots was asked to navigate around the same circuit of checkpoints using the same GPS receiver, moving map display, and sectional chart. This group of pilots was asked to perform one additional task while making their way around the circuit of checkpoints. The experimenter asked each pilot to choose and point out any three geographical features of interest between each pair of checkpoints in the circuit – a total of fifteen geographical features for the entire circuit of checkpoints. It was explained to each pilot that the purpose of this task was to prevent the pilot and experimenter from becoming bored during the flight. The pilot did not need to possess or look up any information about the geographical features, just simply choose and point out interesting-looking features along the way.

In terms of the deep vs. shallow processing hypothesis, pilots who point out geographical features represent a middle ground: these pilots are neither wholly burdened with the navigation task, nor wholly excused from it. If we compare the performance of this third group of pilots to the performance of the two groups from the earlier study, a number of questions can be answered. Is the cognitive effort required to choose and point out geographical features sufficient to avoid the out-of-the-loop phenomenon observed among users of GPS and moving maps? How does the navigational awareness of these pilots compare to that of pilots who navigate using more labor-intensive pilotage methods? How does their awareness compare to that of pilots who relied solely on GPS? Can the practice of pointing out geographical features serve as a practical technique for VFR pilots who use GPS and moving maps?

Method

Participants

The same criteria used in the previous study were used to recruit additional eight pilots. All pilots were legally qualified to act as pilot in command in the experiment airplane. All pilots had basic familiarity with GPS receivers and moving maps. All pilots reported that they did not have significant familiarity or experience with the area in which the data were to be collected (Casner, 2005).

Apparatus

The same Diamond DA40 (Diamond Star) equipped with a panel-mounted GPS receiver and a color moving map display was used for data collection. All pilots were given a current San Francisco sectional aeronautical chart that covered the area through which the experimental flight was conducted. The experimenter used an additional GPS receiver, hidden from pilots' view, to measure navigational accuracy (Casner, 2005).

Procedure

As with the earlier study, the data were collected in Northern California, during July and August, under VFR conditions with a reported visibility of greater than six statute miles (P6SM) at all nearby airports. Prior to engine start, the eight pilots were given a briefing similar to that given to the pilots from the earlier study (Casner, 2005). Pilots were told that the flight would require them to navigate along a series of nine cross-country checkpoints. A sectional aeronautical chart was used to point out each of the checkpoints. Pilots were told that the first three checkpoints were to be considered practice checkpoints, and that the last six checkpoints, shown in Figure 1, were the ones of interest to the experimenter.

Pilots were instructed to fly over each checkpoint as accurately as possible, and to report when they believed that they were directly over each checkpoint. Pilots were free to choose altitudes appropriate for VFR flight at their discretion.

All eight pilots had available a sectional chart and a GPS with a color moving map display. The experimenter confirmed that each pilot was familiar with the basic features of the GPS and moving map prior to departure. The series of nine checkpoints was programmed into the GPS prior to takeoff.

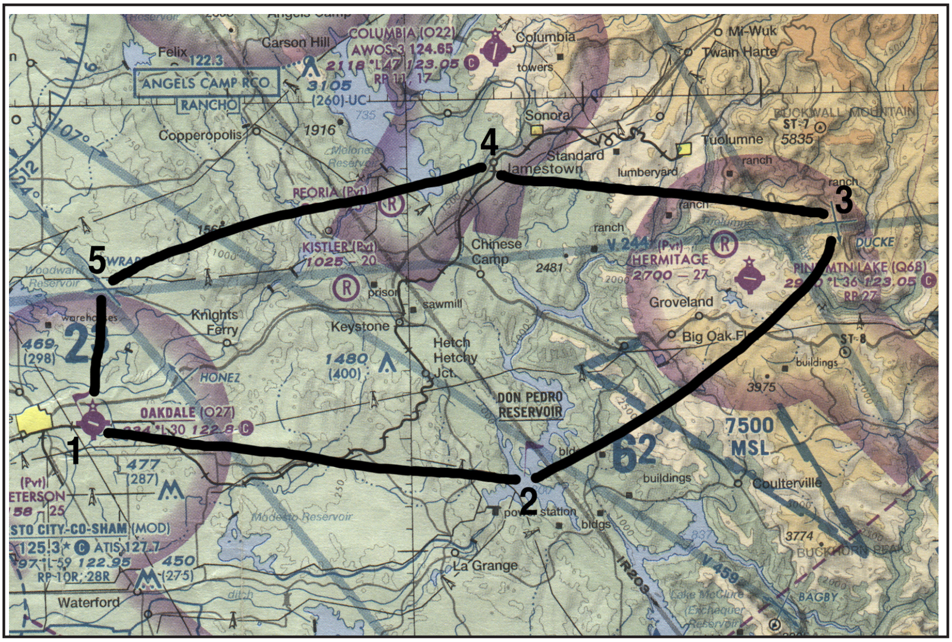

Figure 1. Sectional chart showing the circuit of six checkpoints used in the present and earlier study (Casner, 2005).

En route to each checkpoint, pilots were asked to choose and point out three geographical features of interest. Pilots were told that they did not have to know anything about the geographical features they pointed out, or look up any information about them.

As pilots reported reaching each checkpoint, the experimenter used a second GPS receiver, hidden from the pilot's view, to record the true distance from the checkpoint.

After completing the circuit of six checkpoints shown in Figure 1, the experimenter took away the sectional chart, turned off the GPS and moving map, and (unexpectedly) asked each pilot to fly the circuit of six checkpoints again.

The eight pilots flew over the loop of six checkpoints once again, reported crossing each checkpoint, while the experimenter again noted the navigational error at each checkpoint.

At the conclusion of the flight, pilots were debriefed on the purpose of the study. The importance of remaining actively involved in the navigational process was emphasized with all pilots.

Results

The purpose of the present study was to measure the effect of pointing out geographical features of interest on navigational awareness among users of GPS and moving maps. For this reason, the results for this group of pilots are compared to the two groups from Casner (2005). Thus, the analyses below present data for three groups:

1. Pilotage: Pilots who used sectional charts only [from Casner, 2005];
2. GPS/Map: Pilots who used sectional charts, GPS, and moving maps [from Casner, 2005];
3. GPS/Map with Callouts: Pilots who used sectional charts, GPS, moving maps, and pointed out geographical features of interest.

Navigation Error: First Pass

The graph in Figure 2 shows the mean navigational errors during the first pass through the checkpoints for the three groups of pilots.

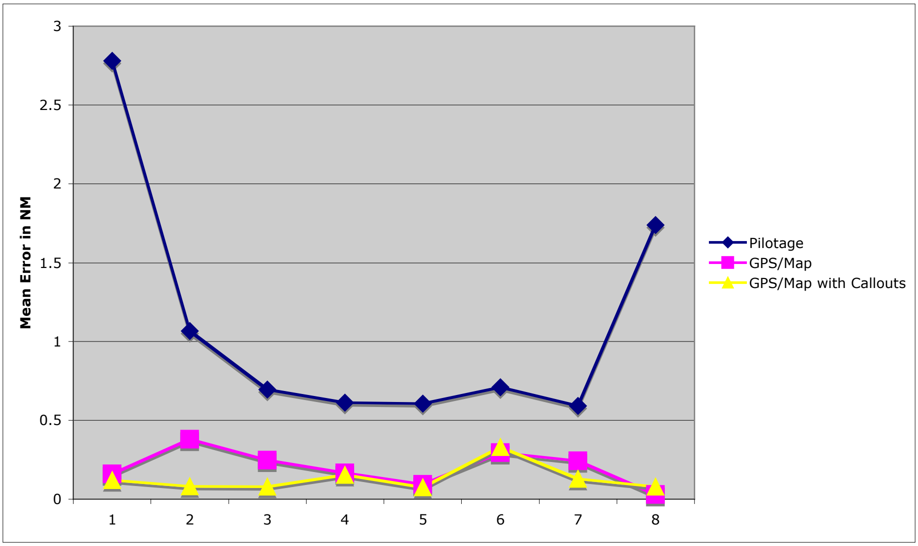

Figure 2. Navigational accuracy with all navigational resources available.

The mean navigational error and standard deviation for the three groups were: Pilotage = 1.1 NM (1.5 NM); GPS/Map = 0.2 NM (0.3 NM); and GPS/Map with Callouts = 0.13 NM (0.7 NM).

During the first pass through the circuit, with all navigational resources available, the group that pointed out geographical features was statistically indistinguishable from the GPS/Map group in the previous study that did not point out geographical features. The GPS/Map with Callouts group performed as well as the GPS/Map group, and significantly better than the Pilotage group ($t = 3.48$, $p < 0.01$), although all three groups performed within the 3 NM navigation standard for pilotage and dead reckoning cited in the Private Pilot Practical Test Standard (FAA, 2002).

Navigation Error: Second Pass

The graph in Figure 3 shows the mean navigational errors during the second pass through the circuit for all three groups: when pilots had all navigation resources taken away from them.

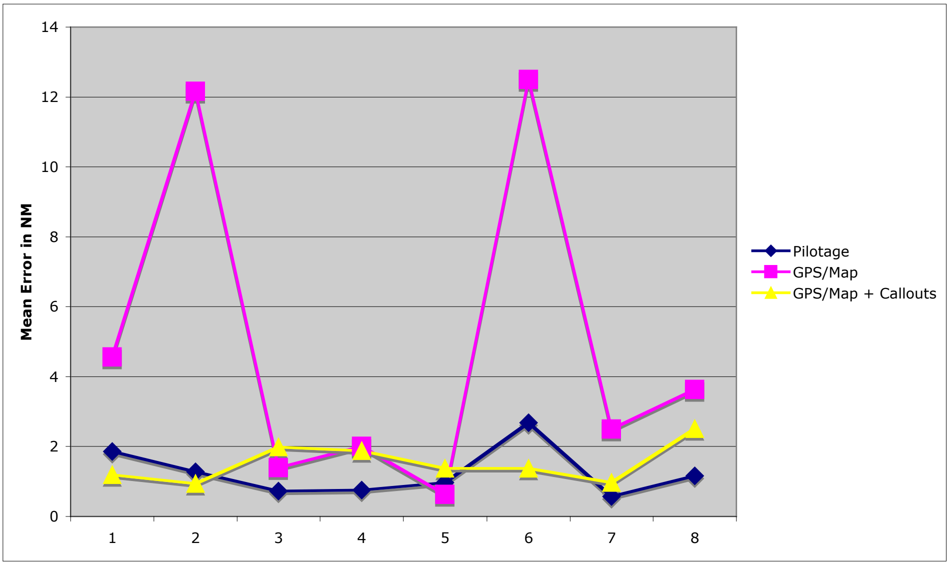

Figure 3. The mean navigational errors during the second pass through

The data in Figure 3 show that the practice of choosing and pointing out geographical features resulted in a significant improvement in navigational performance for users of GPS and moving maps. While the mean navigational error for the GPS/Map group was 4.92 NM (7.92 NM), navigational error for the GPS/Map group that pointed out geographical features was 1.53 NM (1.42 NM).

Figure 4 summarizes, in a single graph, the navigational performance of all three groups with and without navigational resources available. Indeed, it appears that the simple task of choosing and pointing out geographical features significantly lessens the "out-of-the-loop" effect suffered by GPS and moving map users.

As with the two groups of pilots from the previous study, the eight pilots recruited from the present study varied widely in their total flight experience [min = 160 hours; max = 8800 hours; mean = 1968 hours; median = 815 hours]. There were no significant differences for total flight time between any of the three groups compared here, or significant correlation between flight time and navigational performance.

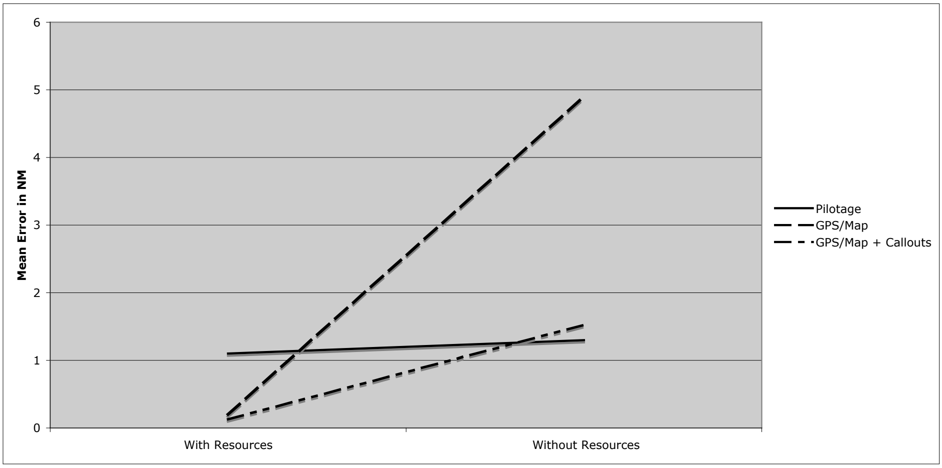

Figure 4. Navigational performance of all three groups with and without navigational resources available

Conclusion

The data show that pilots who use GPS and moving maps, and who invest the time to take note of geographical features along their route of flight, exhibit a level of navigational awareness that is higher than pilots who make no such effort. This finding suggests two things: (1) there are practical techniques that can help mitigate the loss-of-awareness phenomenon observed among pilots who use GPS and moving maps; and (2) a more active pilot involvement in the navigation task seems to be the key to maintaining navigational awareness. What is perhaps most interesting about the result is how such a simple practice of pointing out geographical features was sufficient to make such a striking difference in pilot awareness. This suggests that navigational awareness is indeed a fragile phenomenon.

While it is tempting to conclude that the simple technique of pointing out geographical features represents the solution to the loss-of-awareness problem, we must refrain from doing so for a number of reasons. First, only a small sample of pilots was tested (eight pilots per group). Two of the eight pilots who passively used the GPS and moving map got lost. While it is fair to suggest that the practice of pointing out geographical features lowers the likelihood of getting lost to something less than one-in-four, it is an open question of what would happen if a hundred or a thousand pilots were to complete the study. Second, the measure of navigational awareness used for the study is far from comprehensive. In all conditions, pilots were asked to perform the relatively straightforward task of navigating along the same route a second time. Thorndyke and Hayes-Roth (1982) nicely demonstrate the difference between acquiring knowledge required to replicate a route and acquiring the knowledge required to solve more generalized navigation problems such as finding one's way to a different destination, or finding a different route to the same destination. To what extent the familiarity gained by pilots who pointed out geographical features would serve to solve more complex (and realistic) navigational problems deserves future study. Third, the technique of pointing out geographical features is simply not possible in all situations. For example, it is generally not possible to see geographical features when flying in instrument meteorological conditions. Even under visual meteorological conditions, other cockpit duties (e.g., scanning for traffic, configuring avionics, etc.) would often prevent pilots from performing an out-the-window search for geographical features. Hence, there is a need to discover other practical techniques that help pilots maintain navigational awareness.

A future study might systematically consider what kinds of involvement in the navigation task serve to keep pilots in the loop. Parasuraman (1996) reviews a number of studies that explore different techniques for sharing duties between human operator and automated system. In addition, working with context-rich information such as geographical features yields results that are different from working with more abstract information such as bearings and distances. A better understanding of these factors might contribute to the design of effective practices for maintaining awareness.

The results reiterate the distinction between navigational awareness existing in the storage registers of a computer and navigational awareness actively circulating in the head of the pilot. Casner (2005) demonstrated the consequences for the case in which the GPS and moving map become inoperative or unavailable. Riley (1996) reviews a number of problems that can occur when human operator and automated system have differing assessments of a task in progress – when both entities are operational. Riley identified a number of factors that can cause human operators to disregard the indications of an automated system in favor of their own mistaken beliefs, or disregard their own accurate beliefs in favor of the erroneous indications of an automated system. These findings suggest that, as long as the task of navigating an aircraft is shared between human operator and automated system, it is not acceptable to place all of the responsibility for maintaining navigation awareness on a GPS receiver or similar device. Pilots, flight instructors, evaluators, and policymakers have long talked about the importance of "staying in the loop" while flying with automation. Perhaps now is a good time to make explicit proficiency standards for navigational awareness in the technically advanced cockpit.

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